AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

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CCLXVI.

(Vol. XII.—November, 1883.)

THE COST OF STEAM POWER.

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READ AT THE ANNUAL CONVENTION, ST. PAUL, MINN., JUNE 19TH, 1883.

WITH DISCUSSION.

It is believed that civil engineers require at times general information as to the cost of steam power, which is not readily accessible to those who have not made the subject a special study. This consideration has led the writer to present to the Society, with explanations, the accompanying tabular statement, marked "Schedule A," the greater portion of which was prepared within two years for use in a suit in which two of the referees were Messrs. James B. Francis and E. D. Leavitt, Members of the Society, respecting the loss of power to a series of mills due to the use of a portion of the water for city purposes. Certain features of the table will be better understood by the explanation that it was claimed by the owners of the water privilege that damages should

be based on the cost of purchasing, operating and maintaining, at each mill, a small engine, and a complete independent steam plant, which would at all times just make up the deficiency; while we who represented the city urged that the engines already in the mills should be worked a trifle harder, and that the damages would be represented by a capitalization of the cost of the extra fuel and of a portion of the cost of operation, repairs and renewals, though provision was made for including a portion of the original cost of machinery.

The use of water commenced on the first day of January, 1874, so the costs are all referred to that date. Some of the features of the table are revised, according to the experience of the writer, from a number of elaborate tables presented for the mill owners on the trial by Mr. J. C. Hoadley, M. E. The costs of the machinery given by him corresponded very closely with ruling prices collected for the Novelty Iron Works, New York, in the years 1873-4, and were adopted, except that the prices of the small engines were increased slightly to allow for the application of a fixed cut-off, which was proper if the theory of the mill owners prevailed that a small fixed quantity of power was to be restored at each fall corresponding to the power available with the water condemned. This provision affects the comparison with the ordinary commercial cost of power in small engines in manner hereinafter indicated.

The table shows the various items of the cost of steam power per horse power per year, and also the present value of steam power maintained forever, when produced in small or large quantities. Some presentations, made in particular form to meet the issues in the particular case, have been retained as being of interest.

It will only be attempted at this time to fix upon the minds of those present the governing influences which affect the cost of steam power, referring to the headings which show clearly the several items upon which the final determinations are based.

As a general result it will be observed that steam power costs proportionately very much more in small than in large quantities. The great difference shown in the table is largely due to the fact that the whole time of an engineer is charged to the cost of the power both for the small and the large engines. In some kinds of business the engineer can properly have other duties, which should be considered. Independent of this, however, small engines and boilers are much less economical than larger ones, so that the cost of fuel is much larger even at a fixed price

pe ton, as per comparison in table, whereas commercially the price of the fuel in small quantities is also greater, and would further increase the proportionate cost. All other items of cost are also proportionally greater for small powers. Referring to the table, the engines are rated by the dynamometric power, col. 1, or the power each will deliver independent of its own friction, shown in col. 7; which latter varies from 20 to 9½ per cent. of the indicated power, or that developed in the cylinder, shown in col. 8.

The costs in feed water evaporated into steam, per indicated horse power per hour, col. 9, and the weights of water evaporated per pound of coal, col. 10, are mostly based on experiments made from time to time by the writer with engines and boilers of various sizes, and correspond well with experiments made by others. From these the coal per indicated horse power per hour, col. 11, is obtained, and, as will be seen, varies from 5.6 pounds to 2.52 pounds, according to the size of the engine. The results shown for the smaller engines are even better than will, on the average, be obtained commercially, as they apply to the particular case of an engine of proper size developing a fixed power and operating expansively, as previously explained. In ordinary practice these engines are generally too large for the work, and can rarely be operated expansively, under which circumstances the amount of coal used for the first five sizes should be increased 25 per cent.

The costs in fuel, per horse power, given for the 50-horse power non-condensing engine, can readily be obtained continuously with good engines, of from 50 to 100 horse power, and are, therefore, correct for the particular conditions, but in average practice these engines are often too large for their work, and an addition of 10 to 15 per cent. to the costs given would more nearly represent ordinary commercial results.

The costs given for condensing engines are readily obtainable, but the writer once tested a pair of 100-horse power engines which required 30 pounds of feed water per horse power per hour. The steam was wet and the governor not in good order, which explains the low duty, but illustrates that high ones are not always obtained in practice. The table shows correctly, however, the cost of fuel per horse power in large eastern mills with double condensing engines of 150 to 300 horse power each, the costs being derived from the actual coal consumed and power developed for a series of years, as testified to in court by several different parties from different mills.

It may be added that still better results have been obtained with compound engines, particularly marine and pumping engines, but for mill purposes the designs have too often been undertaken by incompetent persons, who, it is true, caused the steam to exhaust from one cylinder to another, but neglected details necessary to success, and so obtained no better results than those given with the better class of single engines.

Col. 13 makes provision for insurance on the plant at the low rate attainable by the mutual plan, and col. 14 provides for taxation at the rate named in the heading.

In columns 15 and 17 an attempt is made to graduate the pay of the engineer and provide for the number of firemen necessary for engines of the different powers mentioned, the engineer acting as his own fireman for the smaller powers. One fireman is considered sufficient up to 300 horse power; for 400 horse power provision is made for a boy to assist the fireman, and for 500 horse power pay for two firemen is provided. These provisions cannot be considered exact for all conditions, but approximately show the law of decrease of cost of labor as the power is increased.

The cost of supplies, viz., oil, waste, packing, etc., col. 19, was derived from the reports of several steam mills. These items I find less, as they should be, than those reported for short stroke marine engines. In col. 21 the writer has adopted the estimate of the mill owners as to the cost of the usual repairs.

In col. 23 the operating expenses mentioned, with the exception of the coal, are summed, and amount, as shown in col. 24, to $131.13 per horse power per year for the 5-horse power engine, and $7.64 per horse power per year for the 500-horse power engine.

In col. 25 are shown the costs of the coal on the basis of $4.17 per ton, including cartage, which was the price established as an average for a number of years at a particular location near the seaboard, and can readily be corrected for average prices at any other location. The cost of fuel, per table, varies from $45.33 per horse power per year for the 5-horse power engine to $18.02 for the 500-horse power engine. This item for the smaller engines would, in most cases, need to be increased, for reasons previously mentioned.

The several items are summed in cols. 27 and 28, and from the latter it will be seen that the total cost of a horse power for one year is $176.46 for the 5-horse power engine, and $25.66 for the 500-horse power engine.

An item for interest properly belongs in the current expenses, but has been omitted in this branch of the subject, as it is complicated with the question of renewals. In most cases it will be proper to charge simple interest on the cost of the plant, in addition to a yearly annuity, which, if invested, will produce an amount sufficient for renewal in a definite period of years.

In the other branch of the subject, for the purpose of estimating the present value of a horse power maintained continuously, complete renewals are assumed to be necessary every 30 years, when, as shown in col. 5, the present value of the cost of renewals on a 6 per cent. basis becomes 21.08 per cent. of the original cost, and this summed with the original cost, and the capitalization (assumed also at 6 per cent.) of operating expenses and of cost of coal, cols. 29 and 30, gives the totals in col. 31, from which are derived the present values of the total cost of a horse power maintained forever, when the same is generated in small and in large quantities.

The result shows that steam power in sufficient quantity may be maintained forever by an outlay of $660 per horse power, a portion of which would be expended for plant, and the balance invested to provide for operating expenses and renewals.

It thus appears that for ruling prices given, water power cannot compete with steam power when the present value of all proposed improvements, together with the capitalization of the cost of repairs and renewals, exceeds $660 per horse power. Even then the water power should be continuous the year round, or a duplicate plant may be necessary, and the justifiable amount for permanent improvements to secure water power be greatly diminished.

In this connection, a brief extract from a memorandum of the writer on the subject will probably be of interest.

The value of a waterfall in a given location for power purposes depends upon a variety of conditions, such as the cost of permanent plant to make the power available, the quantity of power that can be obtained compared with the work to be done, and, in a very important, if not the most important degree, upon the reliability of the power throughout the entire year and continuously for a series of years.

For a country saw-mill operated by men having other duties at times, a simple torrent, dry or nearly so at times during the summer, will answer very well. The farmers' boys can get in their harvests in the dry

season, get out and haul logs before the snow melts, and saw them by the water power when the stream is full. Everything is of the simplest description; no labor is left idle, and the cost of the whole plant is so small that the mill may be unused for long periods without a loss worthy of consideration.

Such a state of things is not possible with the manufacturing interests of modern times. Large contracts are to be filled; large numbers of operatives are employed, skilled only in particular branches of the particular work done; hundreds of thousands of dollars of capital are invested—the mills cannot be stopped if the owners hope to compete with others doing business in a business way. If the water power fails for a season, steam is employed, and indeed, from its greater reliability, steam is used exclusively in many cases in successful competition with water power. Even the country saw-mills are giving way in many localities to a steam mill in the woods close to the logs, using the slabs for fuel, and teaming out only finished lumber.

The value of a water power is then most readily measured by the cost of the same amount of steam power. The comparison naturally resolves itself into a progressive series from full water power to full steam power, which may be briefly stated as follows:

I. Water power is most valuable when there is an ample supply at all times; that is, when water is abundant and cheap. Even if there be a small diminution for a small portion of the year, a part of the machinery and capital must be idle, and the output and profits of the establishment be proportionately reduced.

II. Water power ceases to be of considerable value when the variations in the power available form a considerable proportion of the total power required. Manufacturers in such locations, in order to furnish products to compete with others, are forced to use, in addition to the water, steam power amply sufficient to supply all deficiencies. When the variations are large, the steam power becomes the main-stay, and the water is used simply to save fuel. The water power is less valuable than in previous cases, because the plant for two different systems must be constructed and maintained.

III. The only remaining step is to discard the water power altogether. When such power is very unreliable, the interest on the plant and cost of maintenance will equal, or nearly equal, the cost of the fuel necessary

ESTIMATES OF COST OF STEAM ENGINES AND BOILERS COMPLET

1	2	3	4	5	6	7
Power of Engine.		Estimated Original Costs.				D
Dynamometric Horse Power.	Kind of Engine.	Cost of Engine and Boiler and all appurtenances, set up in Massachusetts, on the first day of January, 1874, including foundations, boiler settings, pipes, gauges, tools, etc., not including Engine and Boiler House and Chimney.	Cost of Engine and Boiler House and Chimney.	Present value of the Cost of Renewing the Engine, Boiler and all appurtenances every thirty years. 21.0837 per ct. of col. 3.	Total, including Cost of Engine and Boiler and investment for renewal, excluding Buildings and Chimneys. Sum of cols. 3 and 5.	Percentage of Friction of Engine.
H. P.		Dollars.	Dollars.	Dollars.	Dollars.	Per c
5	Portable Upright,	645	313	135.98	781	20
10	" "	988	408	208.28	1 196	20
15	" "	1 487	504	313.48	1 800	18
20	" Horizontal,	1 981	589	417.62	2 399	15
25	" "	2 441	699	514.60	2 955	14
50	Stationary, Non-Condensing,	5 331	1 029	1 123.85	6 455	12
100	Condensing Single,	9 207	1 487	1 940.96	11 148	11
150	" "	13 046	2 129	2 750.28	15 796	10
200	" "	16 785	2 745	3 538.51	20 324	9.[illegible]
250	" "	20 426	3 304	4 306.09	24 732	9.[illegible]
300	" "	23 899	3 841	5 038.24	28 937	9.[illegible]
400	" "	29 958	5 722	6 315.57	36 274	9.[illegible]
500	" "	36 220	7 260	7 635.68	43 856	9[illegible]

SCHEDULE A.

D BOILERS COMPLETE, AND OF THE COST OF OPERATING THE SAME FOR 309 DAYS IN THE YEAR, INCLUDING REPAIRS AND RENEWALS, ON THE BA
AND COAL AT $4.17 PER TON, DELIVERED ON THE PREMISES.

By Charles E. Emery, Ph.D.

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
l Costs.		Data for Calculating Operating Expenses.						Operating and other Current Expenses.												
	Total, including Cost of Engine and Boiler and investment for renewal, excluding Buildings and Chimneys.	Percentage of Friction of Engine.	Indicated Horse Power.	Feed Water per indicated Horse Power per hour	Feed Water evaporated in Boilers per pound of Coal.	Coal per indicated Horse Power per hour.	Total Coal per day of 10 hours, with 1-8 added for starting and banking fires.	Insurance.—Yearly cost at the rate of 1-2 of 1 per cent. on total valuation in col. 3.	Taxation.—Yearly cost at the rate of $15 per M. on 75 per cent. of total amount in col. 3.	Engineer.		Firemen.		Supplies, Oil, Waste, Packing, &c.		Repairs—ordinary and extraordinary — including grates and flues.		Total cost of operating and other current expenses, except coal.		Cost Coal at includ per ton
per . 3.	Sum of cols. 3 and 5.									Per day.	Per year of 309 days.	Per day.	Per year of 309 days.	Per day.	Per year of 309 days.	Per day.	Per year of 309 days.	Per year. Sum of cols. 13, 14, 16, 18, 20 and 22.	Per Horse Power per year.	Per year of
s.	Dollars.	Per ct.	I. H. P.	Pounds.	Pounds.	Pounds.	Pounds.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Doll
.98	781	20	6.25	42	7 5	5.60	394	3.23	9.68	1.75	540.75			.20	61.80	.13	40.17	655.63	131.13	22
.28	1 196	20	12.50	38	7.5	5.10	717	4.94	14.82	1.75	540.75			.25	77.25	.16	49.44	687.20	68.72	41
.48	1 800	18	18.29	36	7.5	4.80	988	7.44	22.31	2.00	618.00			.27	83.43	.17	52.53	783.71	52.25	56
.62	2 399	15	23.53	34	8	4.25	1 125	9.91	29.72	2.00	618.00			.30	92.70	.22	67.98	818.31	40.92	64
.60	2 955	14	29.07	32	8	4.00	1 308	12.21	36.62	2.25	695.25			.33	101.97	.27	83.43	929.48	37.18	75
.85	6 455	12	56.82	27	8.25	3.27	2 091	26.66	79.97	2.00	618.00	1.40	432.60	.36	111.24	.44	135.96	1 404.43	28.09	1 20
.96	11 148	11	112.36	23	8.8	2 61	3 300	46.04	138.11	2.25	695.25	1.50	463.50	.40	123.60	.77	237.93	1 704.43	17.04	1 89
.28	15 796	10	166.67	22.2	8.8	2.52	4 725	65.23	195.69	2.50	772.50	1.50	463 50	.47	145.23	1.00	309.00	1 951.15	13.01	2 71
.51	20 324	9.5	220.99	22.2	8.8	2.52	6 265	83.93	251.78	2.50	772.50	1.50	463.50	.55	169.95	1.24	383.16	2 124.82	10.62	3 60
.09	24 732	9.5	276.24	22.2	8·8	2.52	7 831	102.13	306.39	2.75	849.75	1.50	463.50	.65	200.85	1.47	454.23	2 376.85	9.50	4 50
.24	28 937	9.5	331.49	22.2	8.8	2.52	9 398	119.50	358.49	3.00	927.00	1.50	463.50	.80	247.20	1.70	525.30	2 640.99	8.80	5 40
.57	36 274	9.5	441.99	22.2	8.8	2.52	12 530	149.79	449.37	3.00	927.00	2.25	695.25	.95	293.55	2.20	679.80	3 194.76	7.99	7 20
.68	43 856	9 5	552.49	22.2	8.8	2 52	15 663	181.10	543.30	3.00	927.00	3.00	927.00	1.15	355.35	2.87	886.83	3 820.58	7.64	9 00

SCHEDULE A.

ME FOR 309 DAYS IN THE YEAR, INCLUDING REPAIRS AND RENEWALS, ON THE BASIS OF PRICES FOR ENGINES AND BOILERS RULING IN JANUARY, 1874,
AT $4.17 PER TON, DELIVERED ON THE PREMISES.

By Charles E. Emery, Ph.D.

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Operating and other Current Expenses.															Capitalization at 6 pr. ct.		Sum of original cost and capitalization of operating and other expenses, including investment for renewal.	Present Value of Total Cost per Horse Power maintained continuously, including proportion of original cost of plant, renewals, &c.	
per M. on 75 per cent. of total amount in col. 3.	Engineer.		Firemen.		Supplies, Oil, Waste, Packing, &c.		Repairs—ordinary and extraordinary — including grates and flues.		Total cost of operating and other current expenses, except coal.		Cost of Anthracite Coal at $4.17 per ton, including 25 cents per ton for carting.		Total cost of operating and other current expenses, including coal.		Of Costs, as per col. 23, of operating and other current expenses, except coal.	Of Cost of Coal.			
	Per day.	Per year of 309 days.	Per day.	Per year of 309 days.	Per day.	Per year of 309 days.	Per day.	Per year of 309 days.	Per year. Sum of cols. 13, 14, 16, 18, 20 and 22.	Per Horse Power per year.	Per year of 309 days.	Per Horse Power per year.	Per year of 309 days. Sum of cols. 23 and 25.	Per Horse Power per year. Sum of cols. 24 and 26			Sum of cols. 6, 29 and 30.	Excluding Buildings and Chimneys.	Including Buildings and Chimneys.
llars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.	Dollars.
9.68	1.75	540.75			.20	61.80	.13	40.17	655.63	131.13	226.64	45.33	882.27	176.46	10 927.17	3 777.33	15 485	3 097	3 159
14.82	1.75	540.75			.25	77.25	.16	49.44	687.20	68.72	412.44	41.24	1 099.64	109.96	11 453.67	6 874.00	19 524	1 952	1 993
22.31	2.00	618.00			.27	83.43	.17	52.53	783.71	52.25	568.33	37.89	1 352.04	90.14	13 061.83	9 472.17	24 334	1 622	1 655
29.72	2.00	618.00			.30	92.70	.22	67.98	818.31	40.92	647.14	32.36	1 465.45	73.28	13 638.50	10 785.67	26 823	1 341	1 361
36.62	2.25	695.25			.33	101.97	.27	83.43	929.48	37.18	752.41	30.10	1 681.89	67.28	15 491.33	12 540.17	30 987	1 240	1 268
79.97	2.00	618.00	1.40	432.60	.36	111.24	.44	135.96	1 404.43	28.09	1 202.82	24.06	2 607.25	52.15	23 407.17	20 047.00	49 909	998	1 019
38.11	2.25	695.25	1.50	463.50	.40	123.60	.77	237.93	1 704.43	17.04	1 898.28	18.98	3 602.71	36.02	28 407.17	31 638.00	71 193	712	861
95.69	2.50	772.50	1.50	463 50	.47	145.23	1.00	309.00	1 951.15	13.01	2 718.00	18.12	4 669.15	31.13	32 519.17	45 300.00	93 615	624	766
51.78	2.50	772.50	1.50	463.50	.55	169.95	1.24	383.16	2 124.82	10.62	3 603.86	18.02	5 728.68	28.64	35 413.67	60 064.33	115 802	579	716
06.39	2.75	849.75	1.50	463.50	.65	200.85	1.47	454.23	2 376.85	9.50	4 504.68	18.02	6 881.53	27.52	39 614.17	75 078.00	139 424	558	690
58.49	3.00	927.00	1.50	463.50	.80	247.20	1.70	525.30	2 640.99	8.80	5 406.08	18.02	8 047.07	26.82	44 016.50	90 101.33	163 055	544	672
49.37	3.00	927.00	2.25	695.25	.95	293.55	2.20	679.80	3 194.76	7.99	7 207.72	18.02	10 402.48	26.01	53 246.00	120 128.67	209 649	524	667
43.30	3.00	927.00	3.00	927.00	1.15	355.35	2.87	886.83	3 820.58	7.64	9 009.94	18.02	12 830.52	25.66	63 676.33	150 165.67	257 698	515	660

to produce the same power, and the reliability of the steam makes it the more desirable, and it becomes the sole dependence.

Again, in cotton and woolen mills steam is required for other purposes than power, such as heating the mills, drying the yarn, boiling starch, dyeing, &c., which makes some steam plant necessary in any case; and as in most locations all these operations can be preformed by exhaust steam, all the power obtained from the steam which is used the second time practically costs nothing compared with water power, which reduces the relative value of water power, even under the most favorable conditions referred to in division I, above.

Of course, in all cases the original cost of plant and expenses of maintaining the same must be considered with relation to the water power as well as the steam, and when steam is used in connection with water power, the latter must be charged as much as ever with the cost of the dams, head and flood gates, races, flumes, water-wheels, &c., and the danger from floods and cost of repairs and renewals will not be lessened in the slightest degree.

DISCUSSION.

James B. Francis, M. Am. Soc. C. E.—In the paper read by Mr. Emery, reference is made to a hearing before referees for the settlement of damages for the diversion of water from certain factories in which it had been used as motive power. I happened to be one of the referees in that case, and the paper is substantially the same as one submitted by him, as an expert, at that hearing. The question in reference to which it was then submitted was the cost of supplying, perpetually, an amount of steam power equivalent to that given by the water diverted. One important element in the cost is the periodical renewal of the plant, the allowance to be made for which depends on the length of time assumed for the successive renewals. In the question before the referees the time should be that in which the plant from ordinary wear would become unprofitable to use; renewals usually are made from other causes, notably from a greater power being wanted or from the desire to adopt modern improvements, resulting in greater economy, neither of which could be properly considered in this case. In Mr. Emery's paper thirty years is assumed, but the data for it appear to

be very vague, and it was one of the most troublesome questions on which the referees had to pass. If any of the members can throw any light upon it, I, for one, should be much pleased to hear from them.

E. D. Meier, M. Am. Soc. C. E.—The schedule states the charge for firemen for running a 400 horse power engine to be $2.25 per day; and for running a 500 horse power engine $3 per day.

I am inclined to think that on the larger engines, say from 250-horse power up, the price given in this schedule for a fireman is too low. I should say that for a 400 horse power engine, even at the low rate at which this table is figured, about 2.8 pounds of coal per horse power per hour (which, I suppose, is only possible for anthracite coal, and must be so intended), that the 400-horse power would require two firemen and the 500-horse-power engine about three, and good men at that, worth not less than $1.50 per day each.

Mr. J. F. Holloway.—Availing myself of the kind invitation extended by the Society, I would say that the history of the steam engine in this country does not cover a very great length of time; and we all know that within the past thirty years there have been great changes both in regard to the generation as well as the use of steam; and it would seem from our short experience in the past quite impossible for any one to predict what may be the changes and improvements in the next thirty years. During the five, ten or fifteen years past, very many radical changes have taken place in the construction of boilers, valves, governors, and all the various appliances pertaining to the steam engine, and it would be a rash undertaking for any one to prophesy what the next thirty years may do for it; that being so, I cannot see how one can safely predict what the cost of renewals may be.

It may be, and, indeed, it is quite probable, that very many persons now using engines will find, within the next ten or fifteen years, sufficient reason to warrant them in changing their entire plant.

I think that we have not as yet had a sufficient length of time to establish data by which to estimate with accuracy the time in which renewals must of necessity be made.

Chas. E. Emery, M. Am. Soc. C. E.—If there be no further questions, I will say, first, in regard to the time that should be reckoned for complete renewal, that there is a fairly good allowance made for repairs, which will cover, not entire renewals, but certainly keep the boilers in good condition, and meet the cost of new packing, repairing valves,

etc. There are plenty of engines in the country thirty years old, and running apparently as well as when new. There are not so many boilers, but yet the boilers in many cases last as long as that. In this particular case the expert on the other side had made his estimate for renewal every thirty years, and this not being questioned by the mill-owners could not well be by the city. It is fair to say, though, and the referees discerned it, too, that this time is probably longer than it should be for an average. I think it would be more fair for ordinary practice to take about twenty. The engines last much longer than that on the average, for if one be removed on account of improvements, increase of plant, &c., it generally goes into some other place and is used over again, and may have a run in all of forty years or more. The boilers, however, do not, on the average, last more than twenty years, and when of a peculiar kind may be removed much sooner. The ordinary tubular boiler remains in use sometimes for thirty years, and many boilers are now in good condition which are over twenty years old.

More frequent renewals would simply affect the calculations given in col. 5 of table, and correspondingly change the final summations. For renewal every thirty years, the present value is a little over 21 per cent. of the original cost. This would be increased to 45.31 per cent. for renewal every twenty years.*

In discussing the matter with one of the referees after the award, I found that they had used a short period for renewal, on account of the circumstances at that particular locality. The mill owners were overworking the engines, breakdowns were frequent, and renewals required every few years. Such conditions would not apply where parties started out in business to construct a cotton mill with a certain number of spindles, or a flouring mill, with a given number of run of stone, and put in the power to correspond.

Referring to Mr. Holloway's remarks as to the impossibility of calculating the improvements in steam engines, I have thought of the subject a great deal, but I am not aware of very many improvements in the steam engine for the last twenty or thirty years. They are changing

* If x = present value in relation to principal and n = no. years, for compounding yearly at 6 per cent.:

$$x\,(1.06)^{n} = 1 + x$$
$$x = \frac{1}{(1.06)^{n} - 1}$$

its form, they are putting in novelties in detail, but the results that we obtain are the same, pretty nearly, as those from the original Corliss engine. The trouble is that very much which is called improvement of the steam engine is merely a change of shape; it is like getting the gas into a building by starting at one side and branching toward the other, or by running around in another direction. It is very unfortunate to have to say so, but the greater part of the duties of the engineer of the present day, particularly in regard to steam machinery, is to throw out as worthless or unnecessary most of the novelties, and retain most of the old devices, rather than to take up something grand and new—some improvement which will make a very great advance and a very important change in the amount of fuel consumed per horse power.

The calculations are based upon $1.50 per day for each fireman. This would be $3.00 per day for firemen for a 500-horse power engine, as it would generally be too much work for one fireman. For the 400-horse power engine, allowance was made for a boy to assist one fireman. It is very difficult to make perfect gradations in an estimate of this kind. When there is a little more work than can be attended to by one or two men, it is customary to put in helpers at cheaper rates.

I think I have answered the questions so far as presented.

J. P. Frizell, M. Am. Soc. C. E.—What was the estimate of the length of time per day these engines were to be run?

Mr. Emery.—That is mentioned in one of the headings; see col. 12. "Total coal per day of ten hours, with one-eighth added for starting and banking fires."

Mr. Frizell.—It is customary in this country for flouring mills to run night and day.

Mr. Emery.—That would take off the one-eighth, but it might introduce another element, for the machinery could not be kept in quite as good order when they run so many hours in the week.

The custom in the flouring mills in the East is to run from about 4 o'clock Monday morning to about 8 o'clock Saturday evening. This gives a little opportunity for repairs at night, and they sometimes make Saturday night very long indeed.

Mr. Frizell.—The only time they get to make repairs here is on Sunday.

Mr. Emery.—I suppose the same thing is done elsewhere. It is not always mentioned in that way, though.

Mr. Holloway.—I might add, by way of explanation, that while I would very likely agree with Mr. Emery in regard to what have been the real improvements in steam engineering in the past thirty years, still, when I speak of renewals, I include those instances in which a glibly talking agent comes to a proprietor with a new style of engine, or some new device for generating steam, and by the magic of his eloquence induces him to change his engine on account of some supposed improvement, although, as suggested, the improvement may be like that of bringing gas into a house from some other direction. I claim that if the proprietor does make the change in his engine, or in parts of it, it is really a renewal just as much as if he had worn out his old engine, even if he does not realize the improvement he was led to expect.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

CCLXVII.

(Vol. XII.—November, 1883.)

THE SHUBENACADIE CANAL.

By E. H. Keating, M. Am. Soc. C. E.

Read November 21st, 1883.

This undertaking, although it has so far proved an utter failure in every respect, was at its inception deemed of the utmost importance to the trade and prosperity of the city of Halifax. Its promoters were among the leading men of the country; and it is stated that they were supported in their sanguine views by the most prominent English engineer of the past generation.

It is therefore thought that a brief account of this work may be of interest, and that it should be a valuable lesson to engineers to be extremely cautious as to how they endorse the opinions of other men before making the fullest inquiry into the correctness of the data upon which those opinions may have been founded.

The project was to open communication by water across the centre of the province of Nova Scotia, from Halifax harbor to the Basin of Mines, an arm of the Bay of Fundy.

The chief objects, as set forth by the company which undertook the construction of the canal, were:

1. To establish inland trade and develop the resources of the interior.

2. To enable Halifax more fully to participate in the trade of the ports and districts around the shores of the Bay of Fundy and its branches, by avoiding the long, and sometimes dangerous, sea voyage otherwise necessary.

3. To afford means for the expeditious transport of troops and materials of war from Halifax to New Brunswick and Canada. It was stated that this object would not be fully attained (at least as far as Canada was concerned) until the completion of the Bay Verte Canal, connecting the Bay of Fundy with Northumberland Strait, in the Gulf of St. Lawrence.

4. It was also thought that the canal would, in some mysterious way, give an important impetus to the West India trade.

The works were commenced by the Shubenacadie Canal Company in 1826 with a capital of *£60 000 (subject to be increased) and a donation from the local Legislature of £15 000. In 1829 the Government granted a further concession to the company in the shape of an annuity of £1 500 for ten years.

In a printed statement of the company, issued May 20th, 1829, the total estimated cost was placed at £66 750 6s. 0d., although it seems strange that in the same document appear the estimates of the engineer (Mr. Francis Hall) for the different sections, which, if added together, amount to £90 818 16s. 6d.

The design of the canal was as follows (see Plate):

Length of navigation from Halifax harbor to the mouth of the Shubenacadie River, in the Basin of Mines, 53 miles 1 024 yards.

Fifteen locks, each 87 feet by 22 feet 6 inches, capable of taking vessels drawing 8 feet of water.

The artificial works to occupy only 2 739 yards of the whole line; the remainder to be formed by lakes and the Shubenacadie River.

The aggregate lockage from the tide-waters at Halifax harbor to medium high tides in the Basin of Mines,	Ascending,	95′ 10″
	Descending,	95′ 4″
	Total, -	191′ 2″

The navigation throughout was intended to accommodate vessels

* The £ referred to is the late Nova Scotia pound currency, equal to four-fifths of a pound sterling.

drawing 8 feet of water, and it was stated that the depth of water might be increased, at comparatively small outlay, so that vessels of 11 feet draught could pass through.

It may be of interest to know that the consideration of "this undertaking, with all its details," was submitted to Thomas Telford, the founder of the Institution of Engineers; and in the published statement previously alluded to, it is asserted that "his report, founded upon a minute investigation of the whole subject, pronounces his most favorable opinion of the proceedings and objects of the company." That Mr. Telford had confidence in the success of the scheme would appear from the fact that his name appears on the list of shareholders for £450. He did not, however, visit the country, and it must be presumed that he had no means of forming an opinion other than the representations of those deeply interested in the undertaking—his employers—whose calculations ultimately proved fallacious.

The probable annual revenue, "on the lowest estimate," which the company considered would be forthcoming shortly after opening the canal to traffic, was as follows:

"For Descending Freight.

"Timber and spars, plank, boards, &c., shingles, laths, staves, wharf logs, wood for fuel, tanner's bark, &c., of the value of £20 000, at 15 per cent.	£3 000
"Gypsum and freestone, building materials, lime and bricks, of the value of £12 500, at 10 per cent	1 250
"Hay and straw, salted provisions, flour and meal, grain, fruit, roots, cattle, and other agricultural produce, of the value of £40 000, at 5 per cent	2 000
"For Ascending Freight.	
"Pickled and salted fish, West India produce, British and East India merchandise, &c., of the value of £74 000, at 2½ per cent	1 850
"Amount of annual income	£8 100

"It thus appears that, under a very low rate on the value of the above articles alone, a revenue equal to 10 per cent. on the capital of the company (£60 000) may be soon anticipated, after making a large allowance for repairs, additions, and the expense of management.

"Yet, in the above estimate, neither vessels or passengers, *coal*, nor a variety of other articles are included. *Slate* alone, it is believed, will, when the quarries are fully worked, be productive of tolls to the extent of between £2 000 and £3 000 per annum."

The above quotations from the company's statement will give some idea of the nature and extent of the anticipated traffic through the canal, which, however, was never realized in the smallest degree.

Up to the close of 1831, £72 000 had been expended upon the works. Some of the locks near Halifax had not then been commenced, and much expensive work remained to be done elsewhere on the line. All the available capital being exhausted, the works were abandoned for the time and rapidly fell into ruin. They never were completed on the original plans.

The canal was sold under a foreclosure of mortgage, in 1851, for a debt of £20 000—money advanced to the company by the British Government, under certain conditions, which were not fulfilled—and passed into the hands of the Provincial Government. After having kept the property idle upon their hands for three years, the Government sold it in June, 1854, to the "Inland Navigation Company." In 1856, this company employed an American engineer, Mr. W. H. Talcott, to report upon a scheme for completing the works on a very much smaller scale than was at first proposed. The project now entered upon was to make a canal for boats, 66 feet in length by 16½ feet in width, drawing 4 feet of water; to dispense with five continuous locks at Dartmouth, at the Halifax end, and to substitute an inclined plane with a lift of 55 feet, and a similar plane of 33 feet lift at Porto Bello, each to be worked by hydraulic machinery.

Mr. Talcott's estimate for completing the works on this plan was $69 000. His report, strongly in favor of the scheme, was adopted, and the canal was opened for traffic on this basis in 1862. The cost, however, proved to be about $200 000.

This company, known in 1863 and subsequently as "The Lake and River Navigation Company," undertook the operation of the traffic.

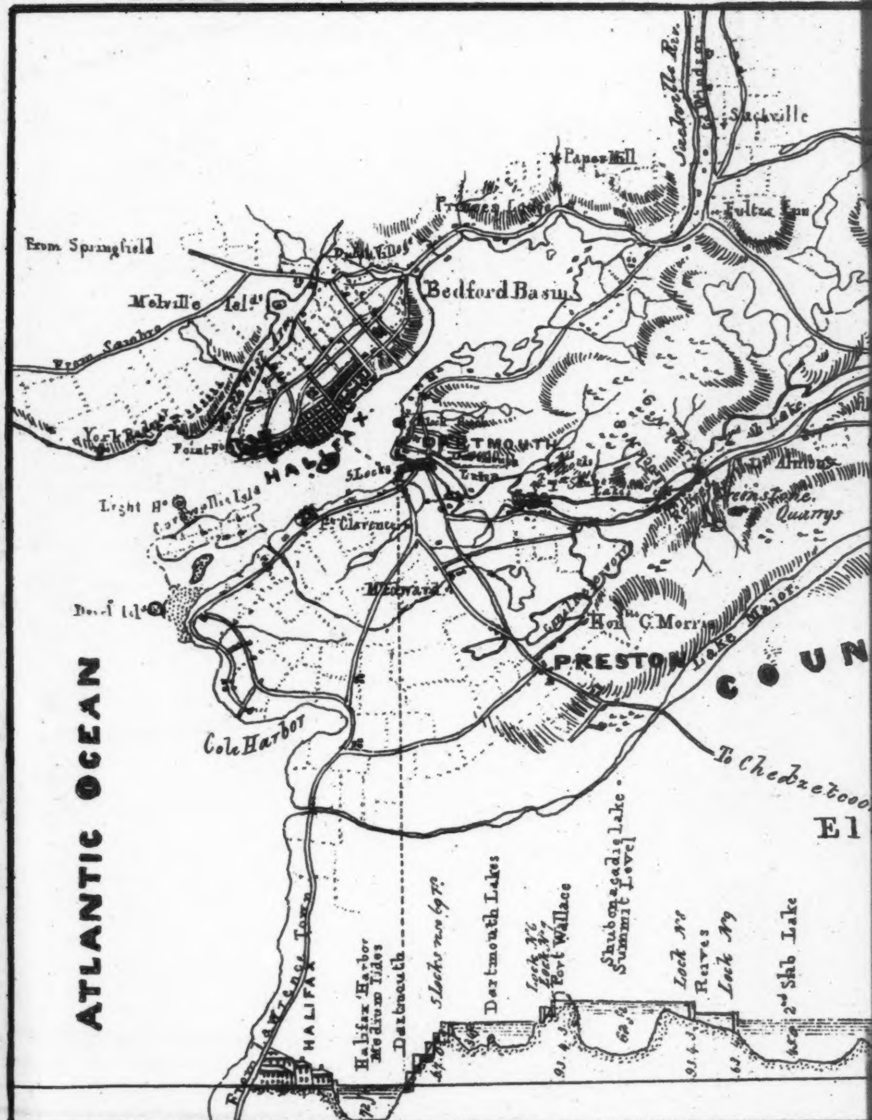
As a commercial enterprise, the diminished canal proved a dreadful failure. Things were no better under the administration of the new company than they had been with others. The canal was not of sufficient capacity to accommodate coasting vessels, or to draw that trade which it otherwise might have taken. The endeavor was made to keep it open

until the year 1870, when the whole of the works, lands and privileges were sold to a private individual for $50 000. Since that date no trade of any kind has been carried on through the canal.

The greatest receipts in tolls for any one year never exceeded $3 000, and in 1870 they had fallen off to $900. The opening up of railways throughout the Province undoubtedly contributed to this result, and to the failure of the scheme.

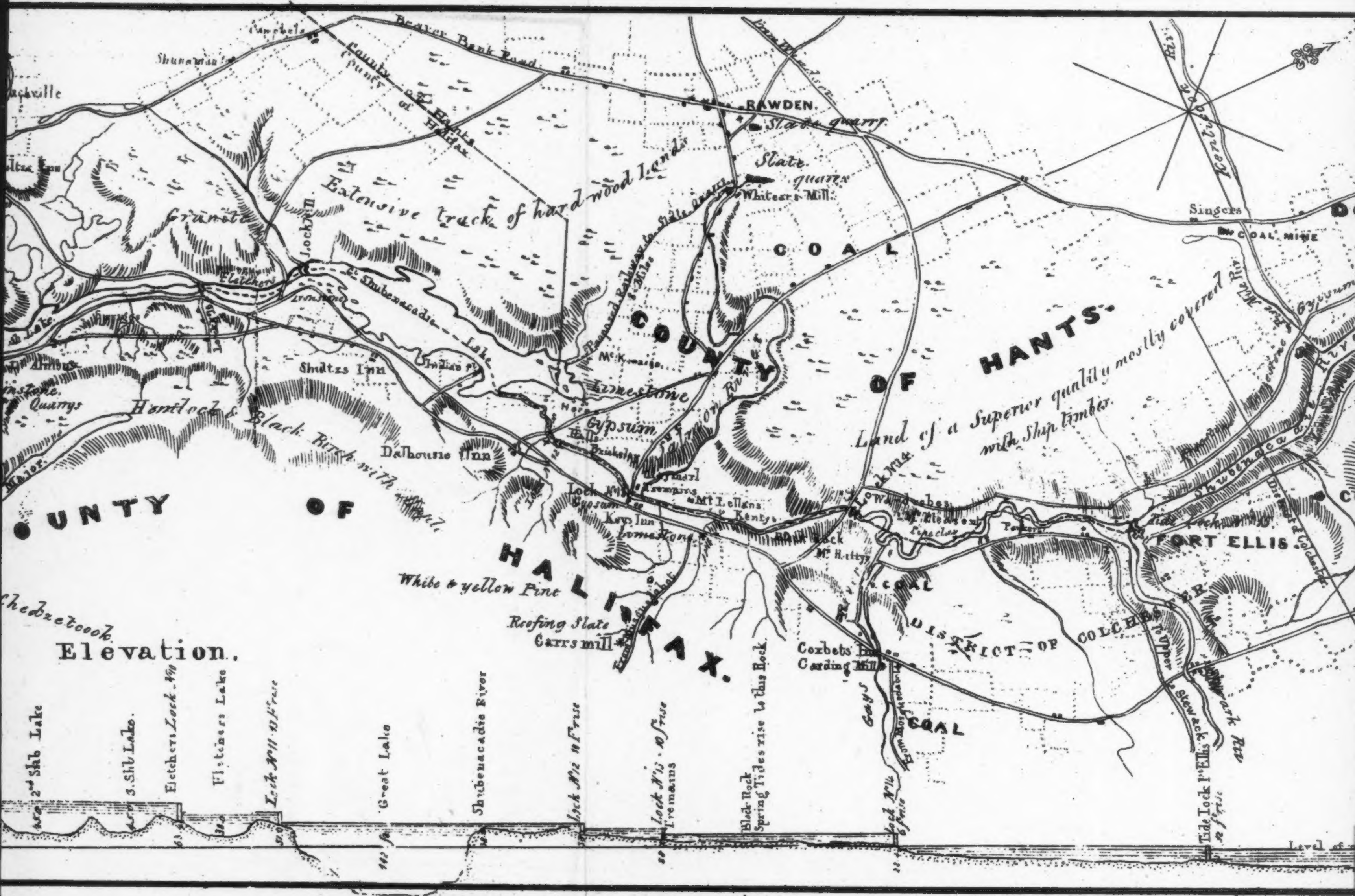
This communication is accompanied with a lithographed plan and plate profile of the works (Plate XXIX).

MAP and ELE



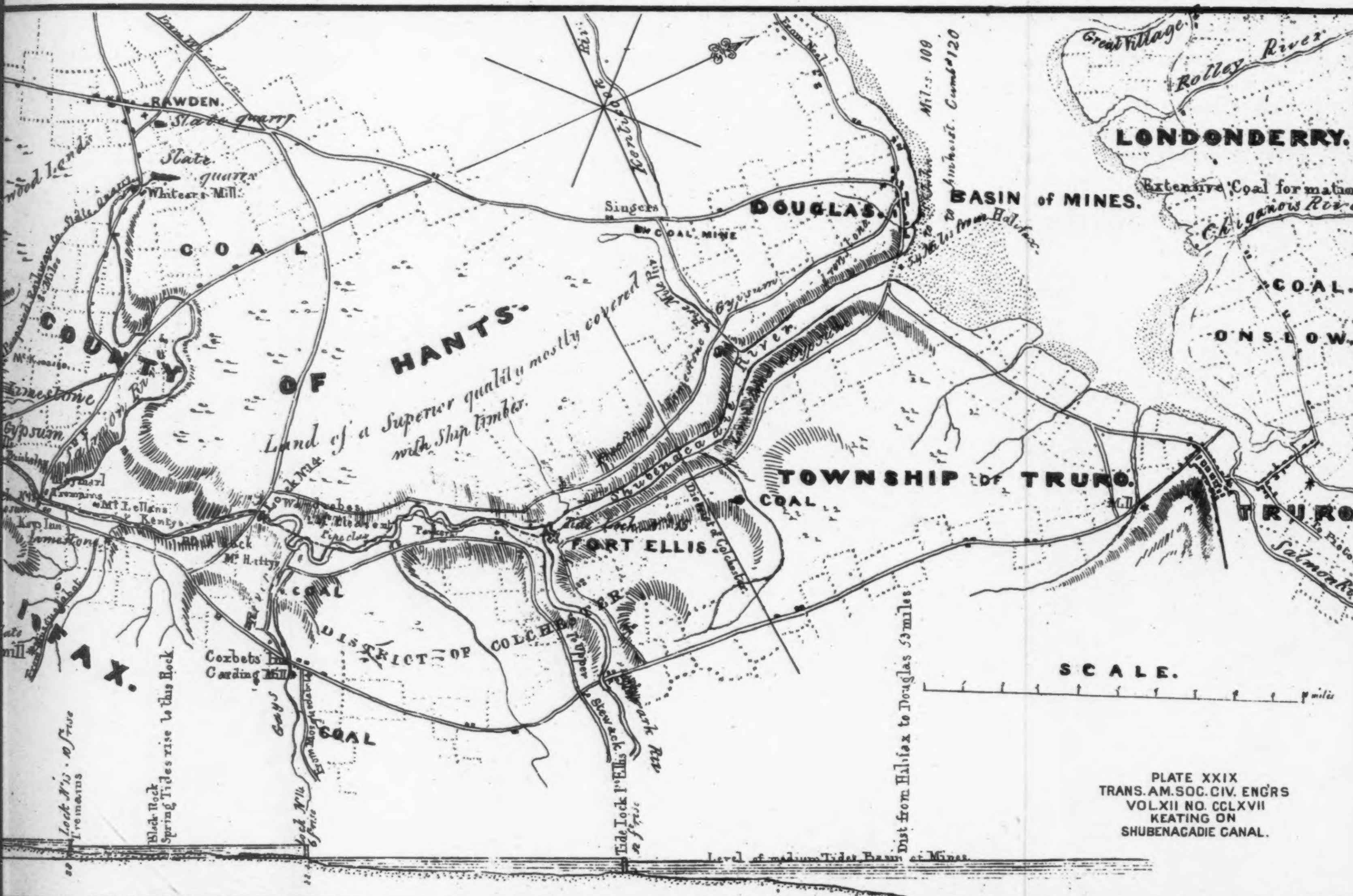
From Springfield
Sackville
Paper Mill
Fultz Inn
Bedford Basin
HALIFAX
DARTMOUTH
5 Locks
Light Ho
Ft Clarence
PRESTON
Lake Major
COUN
Cole Harbor
Quarrys
ATLANTIC OCEAN
El
HALIFAX
Halifax Harbor
Medium Tides
Dartmouth
Dartmouth Lakes
Port Wallace
Shubenacadie Lake
Summit Level
Shb Lake

nd ELEVATION of the SHUBENACADIE NAVIGATION from HALIFAX HARBOUR to the BASIN of M



C. INGREY. LITHOG: 310. STRAND.

AVIGATION from HALIFAX HARBOUR to the BASIN of MINES.



GREY. LITHOG: 310. STRAND.

DRAWN BY F. HALL, ENGR

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INSTITUTED 1852.

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CCLXVIII.

(Vol. XII.—November, 1883.)

ON THE NASMYTH PILE DRIVER.

By D. J. Whittemore, M. Am. Soc. C. E.

Read at the Annual Convention, St. Paul, Minn., June 21st, 1883.

Having used the Nasmyth steam hammer in driving piles in foundations for masonry at the La Crosse and Sabula bridges and for elevator foundations in Milwaukee, it may be proper for me to testify that in my opinion no engineering plant is complete that does not include this appliance, and I fully indorse all that was written in its favor, over thirty years ago, by Wm. J. McAlpine, Past-President of this Society.

I wish to present some evidence of how far the effectiveness of this machine is dependent on keeping a firm head to the pile. Whenever the head of the pile becomes broomed from repeated blows of the hammer, though this brooming may not extend to a greater depth than

from one-half to one inch, the useful effect of the blow is partly lost through the extreme elasticity at the pile head. The following data as to the driving of a green Norway pine pile at Sabula illustrates how far this obtains. The pile was brought to its position between the leaders and dropped through 10 feet of water and penetrated the silt of the river bottom to a depth of 2 feet, and then the hammer commenced its work :

The	3d	foot of	penetration	required	5 blows
"	4th	"	"	"	15 "
"	5th	"	"	"	20 "
"	6th	"	"	"	29 "
"	7th	"	"	"	35 "
"	8th	"	"	"	46 "
"	9th	"	"	"	61 "
"	10th	"	"	"	73 "
"	11th	"	"	"	109 "
"	12th	"	"	"	153 "
"	13th	"	"	"	257 "
"	14th	"	"	"	684 "
		Head adzed off.			
"	15th	foot of	penetration	required	275 "
"	16th	"	"	"	572 "
"	17th	"	"	"	832 "
"	18th	"	"	"	825 "
		Head sawed off.			
"	19th	foot of	penetration	required	213 "
"	20th	"	"	"	275 "
"	21st	"	"	"	371 "
"	22d	"	"	"	378 "
		Total number of blows,			5 228

A pile of about the same size as the one mentioned above, driven near the same locality and to the same depth, but with no adzing or sawing off the head during driving, required 9 923 blows. The ram weighed 2 800 lbs. and dropped 36 inches, 65 times per minute.

At Sabula, about 2 per cent. of the 700 piles driven by this appliance ruptured slightly, just below the ring support at the head of pile,

and the friction produced by the wood fibres working on each other under the repeated blows of the ram was sufficient to ignite and burn the heart of the head of the pile quite across, as will be seen by an examination of the specimen now exhibited.

I add one other remark. This machine is being manufactured and is called, by the manufacturer, after an individual who has added several perhaps very important minor details, that have made it a little more practicable than it was thirty years ago. But wherever the members of the American Society of Civil Engineers witness the operations of this machine, I desire that they shall not drop the name of the Scotchman who is its inventor—James Nasmyth.

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CCLXIX.

(Vol. XII.—November, 1883.)

VIBRATION, OR THE EFFECT OF PASSING TRAINS ON IRON BRIDGES, MASONRY AND OTHER STRUCTURES.

By JAMES L. RANDOLPH, M. Am. Soc. C. E.

READ SEPTEMBER 5TH, 1883.

WITH DISCUSSION.

Having been for some time observing the effect of passing trains on iron bridges, I have decided to commit to paper certain views originating from such observations and submit them to criticism, in order that their truth or error may be elucidated.

I suppose all have noticed that cattle stops and open culverts under railroad tracks, where built of rubble-work, soon have their walls shaken to pieces by the vibrations produced by passing trains. To avoid this, I have been building such structures as bridge masonry with large, heavy stone. Our double-track bridges are moved in the direction of passing trains, consequently are twisted and a strain produced on some of the members which has not been provided for.

The rails in the track on single-track bridges are moved, but so nearly

restored to their position by the trains in the opposite direction that no inconvenience is occasioned except on grades.

Our tall, thin piers and the heads of T abutments, on which iron bridge superstructure rests, have the stone of which they are built so much disarranged by this vibration as to make it necessary to secure them with timber and iron, to strap them up.

Our trestle bridge at Harper's Ferry, in the course of several years, was moved 4 inches toward the river, so much that it was necessary to re-adjust and replace it.

The explanation of these results seems to me to be as follows :

The small walls in open culverts and cattle stops having usually been composed of stone, irregular in size and shape, receive and transmit the vibrations from the trains in different times and directions, depending upon their size, shape and position. On account of the expansion and contraction of the stone (without which they would be inelastic), this vibration drives the outer stone in the direction of least resistance and down the inclined surface, which may be below it, finally out of the wall, there being no power to force a stone up an inclination to its first position.

The remedy is to build such structures of large stone, as nearly the same size as possible, so that the vibrations would be in the same time.

A monolith would be better for the wall, but not so good for the machinery or bridge, for the vibration or the return blow from so heavy a mass would act on the structure above as the anvil on the sledge. The bank, behind the above-mentioned walls, confines their action to one direction, but in tall thin piers this action may take place in every direction, and where set on a solid rock foundation the return blow from this heavy elastic mass meets a fresh blow from the engine and train, the resolution of which forces being at right angles, or in the line of least resistance, the stones near the middle of the wall are forced out of place. There is no force acting in the direction to return them, but particles of mortar falling in the cracks behind them would prevent their return if there was such a force.

We strap them up with beams of wood and bars of iron, preventing further serious movement.

Iron bridges resting on stone pedestals are vibrated in this manner, receiving a return blow from the pedestal which, in very heavy structures, seems to be absorbed.

In light structures this vibration is felt and transmitted to the pedestal, but these two materials, iron and stone, being of different elasticity, do not vibrate in the same time, so that there must be periods, however short, when they are not in contact; a continued impetus in the same direction, during these periods, must result in a movement in the direction of the force.

The Harper's Ferry trestle bridge is composed of girders, supported at each end by cast-iron posts set on stone blocks, set at right angles to the road; these girders support the ends of stringers on which the cross-ties are placed. This trestle forms the approach to the bridge over the Potomac River. There is but one track on the bridge, which is the north track, on which trains go west, and is of course on the river side of the trestle approach. This track is straight along the river, and makes a strong curve on to the bridge. On the straight portion of it, the south track, for trains going east, makes connection with it, consequently every train going east gives this trestle bridge an impetus towards the river, in passing from the south to the north track.

The cast-iron posts under the ends of the girders, vibrating in different times from the stone blocks, on account of difference in elasticity, would lose contact, be separated for infinitely short spaces of time, when being under constant pressure in the same direction, would not return to exactly the same position. This resulted in a movement of 4 inches in about 4 years. I could account for the movement which did take place in no other way. I therefore put a piece of plank from 1 to 2 inches thick between the stone and iron, reasoning that, as it was of different elasticity from either stone or iron, it would remain in contact with both. This was 4 years ago, and there has been no movement since.

I have set all iron bridges of 100 feet span and under on wooden wall plates, and no movement has been observed in them.

Where I had solid rock foundations, sufficiently under water to insure its being always wet, I have put a platform of timber under piers and other masonry which has to carry iron superstructure; I can observe no displacement of stone in such structures.

My theory is, that the stone being nearly uniform in size, the vibrations in each will be in the same time, and that when these vibrations reach the timber they will be absorbed, and not return from the rock to meet succeeding vibrations. There can be little or no elasticity in the

timber under the pressure of the masonry; or, if there is, there is not weight enough to give a return blow, and whatever vibrations may be carried through it are in different times with what may be given to and received from the solid rock foundation; there are none to return up the pier to meet others coming down, thus removing the cause of the displacement of stone in thin piers and other masonry subjected to the action of moving bodies.

The masonry of open culverts and cattle stops will be shaken to pieces in much less time on solid rock foundations than when on clay or gravel.

From all these considerations, I reason that a monolith would be the best support for bridges or other structures subjected to the vibrations caused by passing trains or the working of engines, but the monolith, if of the same specific gravity as granite, would be of such weight as to give a damaging return blow, if sufficiently elastic, acting as an anvil on a sledge, or a Belgian block on the hoof of a horse, etc.

We need a material for this monolith compact enough to resist the pressure, with little elasticity and low specific gravity. Timber would answer the purpose, but it is perishable; it would be inconvenient and expensive to renew it under heavy structures.

The material which, in my opinion, best answers the foregoing conditions—inelastic, light, compact and durable—is artificial stone, such as was used in the construction of the Dry Docks, Erie Basin, Brooklyn, N. Y. This is about two-thirds the weight of granite, sufficiently compact, durable as other stone, and with very little elasticity. In drilling a hole with the churn drill the drill does not rebound.

The pumping engine for these Dry Docks (250 horse power) has been working smoothly for more than one year on an artificial monolith 20 x 24 feet, 12 feet thick.

I am so convinced that this is the best material to receive and dispose of vibrations, that I have built pedestal blocks of it 5 x 6 feet, 2 feet thick, for an iron bridge 155 feet span, the pedestals on each abutment connected by a cross-wall, the two pedestals and one cross-wall making one solid stone, the cross-wall so arranged to act as a strut in the diagonal bracing. Great elasticity is not wanted, for that would cause sinking or a wane under a train equal to a heavy grade. Great weight is not wanted, for that strikes back too hard. I purpose using this material extensively in this manner, unless it is shown that I am wrong.

DISCUSSION.

Theodore Cooper, M. Am. Soc. C. E.—Similar facts to those mentioned by the author of this paper are known to most of us who have to do with such structures. The explanation given by the author appears unnecessary and untenable.

That poor masonry is shaken to pieces by the impacts and strains produced by passing trains, does not require any vibratory theory for its explanation. Neither does the creeping of bridge trusses and girders, any more than the creeping of the rails in a track.

The pull of a heavy engine or the push of a moving train, when subject to the retarding action of the brakes, is an enormous force; which, fortunately, in most cases does not act directly upon the girders or the supporting masonry, or the effects would be still worse than those usually observed. It is largely distributed by the track system, where it is in good order, over a longer distance than that covered by the train only.

In time, however, it is sure to produce visible results upon the substructures that are not proportioned to resist it, through the aid of expansion and contraction, and the occurrence of loose joints. On curves, grades, or tracks where trains run in one direction only, its action is accumulative, and more severe than elsewhere.

The author does not describe fully the character of masonry from which stones are forced out in the manner described in the paper; but the inference is that it was a very ordinary kind of masonry, imperfectly bonded and cemented together; hardly to be compared to what is now usually classed as first or second-class masonry in the best specifications for railroad work.

The general character of the bridges upon the author's road (Baltimore and Ohio Railroad) may have something to do with the severe action upon the masonry which he describes. They are largely of a type (the Bollman truss) rated very low by bridge engineers, and not acceptable by other first-class railroads.

It may also be very probable that this road is about to realize the fact long ago appreciated by other railroads, that the old style of bridges and masonry, first adopted in their construction, is not suited to the continued action of the heavy traffic of the present day.

Grouted masonry is not considered at the present day as a suitable character of masonry to be used, especially for railroad purposes. The

author need not fear the action of a monolith upon his bridges, if they are properly proportioned for the work to come upon them.

The hammering action he speaks of can only occur in very light structures, or where the impacts of the wheels are transmitted immediately to the masonry. As all trusses should be anchored down to the masonry at both ends, even where provision is necessary for expansion, no true hammering can take place. The use of wooden wall-plates under the ends of stringers relieves the pounding at these points, but generally, from the liability to decay of the wood and chances of neglect, it is preferable to provide for this action in other ways.

Charles E. Emery, M. Am. Soc. C. E.—The tone of the discussion on this paper—referring now particularly to the remarks and questions at this meeting—is to the effect that the explanations of the observed phenomena, by the writer of the paper, are untenable, unsatisfactory, or, at the best, unnecessary. Granting without question the statements of Mr. Cooper, that such effects would not result with heavy bridge structures, or more substantial masonry—all proportioned according to later experience and more modern methods—it is, nevertheless, true that very many structures of older types are still in existence, and it is of interest to know how these act under modern circumstances, and how their defects may be remedied, either temporarily or permanently. The first step towards providing a remedy is a philosophical investigation and explanation of the causes of the difficulties. Notwithstanding the criticisms, I consider the explanations given quite sound in principle, and in the main very satisfactorily expressed.

All materials are more or less elastic, and each particular body has its own period of vibration, depending upon its elasticity and the quantity of mass in motion. Even the earth vibrates, not only when supported closely on rock, as at Niagara Falls, but even where there is a bed of sand of great depth, as on Broadway, New York, the vibrations produced by stages on that thoroughfare being felt in the upper part of buildings over 100 feet distant. When the forces producing the vibration intermit in multiples of the period of vibration of a particular structure, the amplitude of the vibrations is greatly increased, often causing danger; for instance, necessitating the well-known regulation that troops shall not keep step on a bridge. Again, the period of vibration of the springs of a parlor car, at certain speeds, corresponds often with the times of meeting rail-joints, causing a very unpleasant dancing

motion, and more frequently the piston strokes of the locomotive become synchronous with a multiple of the period of vibration of the draw-bar springs, and a very uneasy sensation is experienced, often attributed to rough tracks, when the principal vibrations are really longitudinal. In view of the many known phenomena in relation to vibration, the explanations of the author of the paper in relation to the movement of the cast-iron columns of a trestle on their stone foundations seem well founded. It is not, however, necessary to suppose that, on account of different periods of vibration, the surfaces need to "lose contact" and "be separated," even for "infinitely short spaces of time," as is assumed in the paper. The vibrations need only reduce the pressure on the surfaces in contact to such an extent momentarily that the diverting force becomes sufficient to cause a slight movement. When a body is in motion in one direction the slightest lateral force is sufficient to divert it, as the two forces combine to produce motion in a diagonal. This principle, it will be recollected, I utilized in my plan for a hydraulic testing machine, in which, by rapidly revolving the ram, the longitudinal pressures on the same and the specimens were allowed to equalize themselves so well that the indications of a pressure gauge became an accurate measure of the strains imposed. The movement of bridges and other bodies in a particular direction, when subject to jar and to an additional small force acting in that direction, may be similarly explained. The value of the wood is due to the fact that it absorbs the vibrations, and thus leaves the diverting force without the opportunity to combine with another force sufficient to produce movement. The wood serves an additional purpose in preserving the whole structure from injury by the jars. This principle is utilized for trip-hammers, which can only be preserved by erecting them on extensive foundations of wood.

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CCLXX.

(Vol. XII.—November, 1883.)

ON AN ECONOMICAL AND EFFICIENT RAILROAD BRIDGE FLOOR.

By W. HOWARD WHITE, M. Am. Soc. C. E.

READ SEPTEMBER 19TH, 1883.

On asking the late Mr. A. D. Briggs, F. Am. Soc. C. E., Massachusetts Railroad Commissioner, some years ago, certain questions in regard to a form of standard bridge floor, he said that he did not think such a standard could be designed, for the reason that the cases differed so much for which it was needed.

Meaning by the floor the immediate supports of the rails and their appurtenances, consisting ordinarily of the ties and guard rails, I do not

agree with him; for, on examination, I think it will be found that there is practically very little variation in the demands on a railroad bridge floor, or the conditions imposed on it.

It is required in all cases to satisfactorily support and hold in place the rails for the passage of trains; and it should also carry the wheels of a derailed car or train safely over without injury to the bridge itself, and, lastly, it should be as economical of construction and maintenance as consists with the other requirements.

To carry derailed trains over economically, and also, in through bridges, to avoid injury to the bridge, it should keep the derailed wheels close to the rail, and consequently not far from the support provided for the rail, since wandering of the wheels will make necessary a greater spread of floor, and, what is worse, will injure a through bridge by rubbing the cars against the trusses.

These being the requisites, what are the cases in which they are to be fulfilled?

The ordinary bridges on railroads which require what is technically called a floor are:

1st. Wooden stringer bridges with stringers under the rail.

2d. Plate girder or truss bridges with the supports directly under the rail.

3d. Girder or truss bridges with the supporting members so deep as to make it desirable to set them further apart than the width of the rail centres, and arranged with ties acting as floor beams to carry the load to the supporting members.

4th. Girders with ties resting on the lower flange and serving as floor beams.

5th. Deck bridges with a regular floor beam construction, surmounted by stringers.

6th. Through truss bridges with floor beams and stringers.

All of the above are practically stringer bridges, as far as the floor is concerned, except Nos. 3 and 4.

No. 3 is unusual, and I think most engineers will concede undesirable, and always avoidable, even when the head room below is the difficulty, by suspending the floor beams and adding stringers.

No. 4 is sometimes unavoidable, but very rarely so.

The only important difference between wooden and iron stringer or girder bridges lies in the offsets on the top flange of iron girder bridges;

the difficulty from which can be readily met by increasing the depth of the tie, which I hope to be able to show is desirable in any event; and it then appears that one form of bridge floor will answer for all bridges, except the special and infrequent class No. 4.

In meeting the conditions postulated, the first question is the material for the ties. I suppose it will be generally conceded that some variety of wood is desirable, and probably no wood can be had at equally small expense so suitable to stand the cutting action of a derailed wheel flange, as well as for the purpose of holding spikes, as oak.

As to size, the ordinary practice has settled upon 8 inches as the minimum width for sawed ties to hold spikes satisfactorily.

As to thickness, I do not suppose any one would use less than 5½ inches, and, in order to meet the cutting out for offsets on the top flanges, I would add 1 inch, and ½ inch for cutting of rail into tie, making the total thickness 7 inches. This size will saw well out of round sticks, securing straight grain and heart wood.

In applying this on iron girders, we begin at the ends by simply laying the tie over the rivets, striking it with a maul to mark the rivet positions, and slightly boring to give entrance to the rivet-head.

This fitting over the rivet-heads will be found amply sufficient to hold the track in place on the girder.

Towards the centre of the girder, where there are offsets, the ties have to be gained additionally for the increased thickness of the flange.

On wooden stringers, in preference to using line spikes, I think it best to gain the tie ¾ inch over the stringer, thus securing it effectually in place laterally without making holes for water to get into the stringer, and without either leaving spikes sticking up to strike the foot, or notching round them to give a hold for the draw-bar—a disastrous practice for the accumulation of water.

It has been objected that it is difficult to take out single ties under this arrangement; but I think this is fanciful, since the operation can be performed with very little trouble by jacking or prying up the track at the tie in question, taking hold on the guard timber as I propose applying the same; and what extra trouble there may be in this will be more than compensated by the greater durability of the ties in the absence of spikes and notches on top.

As to distance apart of ties, it is desirable, of course, to have as little

jumping of the derailed wheels when running over a bridge as possible, and to this end, I advocate 5 inches clear distance.

This would let a derailed 33-inch wheel drop $\frac{5}{32}$ inch, if the ties were unyielding, whereas 6 inches clear gives $\frac{1}{4}$ inch drop, and 8 inches gives $\frac{7}{16}$ inch.

It might at first sight appear as if $\frac{1}{4}$ inch were insignificant, because the wheel would cut into the tie more than that at any rate, and would consequently meet the edge of the next tie before any drop took place. I think this is fallacious, however, the probability being that the drop increases more than the above figures would show in proportion to the clear distance, owing to the greater cutting at the edges of the ties due to the decreased bearing in leaving one tie and the blow with which it strikes the next one. In fact, it is generally noticeable in the mark of a derailment that both edges of the tie have been cut deeper than the centre.

In regard to the length of a tie, if my theory as to guard rails, given below, is accepted, there appears no reason for making the tie more than the usual 8 feet in length, and, indeed, in through bridges, it is difficult to see on what theory any greater length than 10 feet for single track can be defended ; inasmuch as, if it were made use of for supporting the derailed wheels with any clear width between trusses, which it is usual to give, the trusses would infallibly be destroyed or the cars torn to pieces.

On double-track bridges—either deck or through bridges with but two trusses—it is undoubtedly better to run the ties clear across, to provide for derailments between the tracks and for the greater stability of the bridge, and in this case the thickness of tie I propose, placed so close together, will be found sufficient to carry derailed cars without additional support below.

Proceeding now to the guard timbers or rails—a very important member of the floor—I am strongly in favor of an inside guard, for the following reasons :

1st. It is more efficient for the same height above the tie than the outside guard, and its limiting height (that of the rail) is more efficient than such heights of outside guard as are ordinarily used.

2d. It can be placed so as to hold the wheel nearer the rail than an outside guard of equal efficiency can be, having regard to snow-plows.

3d. It is more readily and strongly secured at the ends for the purpose of drawing the derailed wheels over to the rail, and to secure the ditching of a car that has got off too far to be safely drawn in without danger to the trusses of a through bridge.

4th. It is more economical than any other guard to secure the above objects.

Its greater efficiency is due to its taking a bearing on the flange side instead of the tread side of the wheel, taking in a larger arc of the wheel at the same height, and meeting a rounded edge with a tendency to shear off, instead of a sharp edge with a tendency to cut in.

With an ordinary 33-inch wheel with 1⅝-inch flange, the advantage on account of the larger arc and consequently higher climbing tangent, as shown by the diagram (Plate XXX), makes an inside guard 4 inches high equal to an outside guard 1¼ inches higher ; and this advantage increases for larger wheels and deeper flanges. The advantage due to the meeting with the rounded edge is difficult to estimate, but it can hardly be less than ¾ inch, viz.: an inside guard of 4 inches in height is equal to an outside one of 6 inches for a 33-inch wheel.

As to the second point, efficiency in drawing a derailed wheel close up to the rail, in general it is necessary on account of snow-plows to place a guard higher than the rail some considerable distance outside of it, and since the inside guard is more efficient for the same height, the second point may be considered proved.

As to the third point, it is evident that the inside guards can be brought together, making a strong point, and fastened to the ordinary track ties, while the flare of the outside guards has to be set up independent of the ordinary track structure.

In regard to wheels too far off to be caught and restored to line by inside guards, I would observe that, while it is the practice of some roads to attempt this restoration, it does not seem to be a wise one. Wheels so far off will generally be at such an angle as to make their restoration almost impossible, and if the attempt is unsuccessful, in the case of a through bridge, it would in all probability be destroyed, since no practicable bunter-post that could be put up would arrest with any certainty a car or train at considerable speed.

For this reason, it appears to me better to extend the inside guard far enough beyond the bridge—say, with the point at twice the length of

the inclined portion from the truss end—to throw the car if it took the wrong side of the point clear of the bridge structure.

In case of a high embankment, it would be desirable to carry it still further to a point where ditching would not be too serious an accident.

My fourth point will be proved if the foregoing argument is valid, since the inside guards would take less material and be more easily applied.

As to the material for inside guards, I would say that the use of old rails, as sometimes practiced, appears too expensive for application to all bridges, besides not serving the purpose of keeping the ties properly spaced ; and I have, therefore, in the diagrams appended (Plate XXX), used a 5-inch x 8-inch pine stick (this would be increased to 6-inch x 8-inch for 4½-inch and 5-inch rails), notched down 1 inch over the ties and bolted to every third tie with a ¾-inch bolt. This construction then serves the triple purpose of guard rail ; of keeping the ties properly spaced, and from creeping, by its connection with the ordinary track ties on the bank ends ; and of lifting the superstructure by means of a jack or lever for the purpose of removing ties.

The ends of these sticks I have shown brought together in a straight point 30 feet long, which gives an angle only $2\frac{4}{10}$ times as great as a 20-foot switch rail with 5-inch throw, terminated by a rail point 6 feet long.

The curved points, not uncommonly used, are rather absurd when it is reflected that they give the largest meeting angle with the wheel at the point where the latter is presumably most out of parallel with the track.

There may be some question as to the expediency of using timber in the point, but my impression is that it will be found sufficient, when in good order, to turn a wheel, and as often as it is marred by a derailment or becomes rotten it can be replaced at less capital cost than the iron.

I would note that the Lake Shore and Michigan Southern R. R. uses, or did use some years ago, a bridge floor similar to the one advocated here in size of tie, spacing, and notching of tie over stringer and guard timber over tie, but they use a 13-foot tie, rails for inside guards curved to a point, and a 7-inch x 8-inch outside guard.

This design appears defective in two ways : first, that no provision is made by extending the ties after the point of the inside guard has been passed to carry the outside derailed wheel to the bridge in case the other

wheel takes the wrong side of the point; and secondly, there is not room enough on even these long ties to carry the outside wheel in the position it must take on the bridge when the other wheel has taken the wrong side of the point.

It is evident that if inside guards brought to a point are used, there is no middle course between ditching a train if it takes the wrong side of the point, and the provision of ties long enough, that is, 15 feet, with a stringer under their ends to carry the wheels, in the above contingency.

So far as through bridges are concerned, I think the floor I advocate is the safest possible at any reasonable expense, and in claiming that any more perfect floor is needed for other classes of bridge, it is well to consider how small the chances of accident are for which we are providing at so much extra expense as the increase of the ties to 15 feet in length, and extra stringers under their ends, entails.

I doubt if the experience of all the railroad men in the country would show more than two or three cases where, if inside guards had been used, as proposed, any further precaution would have been of advantage even to freight trains.

The chance of this is as follows:

1st. The comparatively large chance of derailment.

2d. Out of this the far smaller chance of a derailed wheel going more than half gauge distance from the rail. One out of five would, I think, be a high estimate.

3d. That it shall include a bridge in the run of a train while derailed. Two bridges in a mile would be rather a high average, and as the derailments would average a third of a mile in extent, possibly a half, it is about an even chance that a derailment shall cover a bridge.

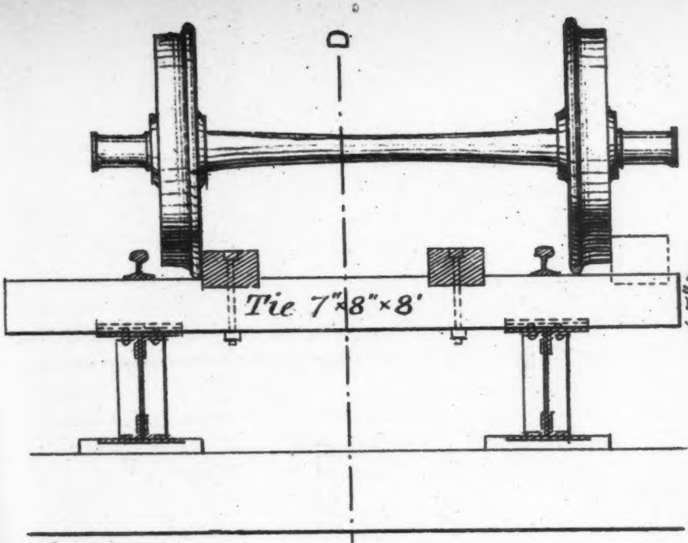
4th. That it shall be a passenger train, say, 1 in 3, and we have 1 in 30, and if we further throw out derailments covering through bridges, which I have shown cannot be helped by wide floors, and bear in mind that passenger derailments are much shorter in extent, and that the connection between the cars is much more close and perfect, probably not one derailment in one hundred will be of a passenger train covering a bridge and having the wheels more than half gauge away from the rail.

I leave freight trains out of account, for I think the chance of 1 in 10 would lead any railroad man to ditch a freight in that proportion of de-

railments rather than incur the expense of providing for it at all bridges.

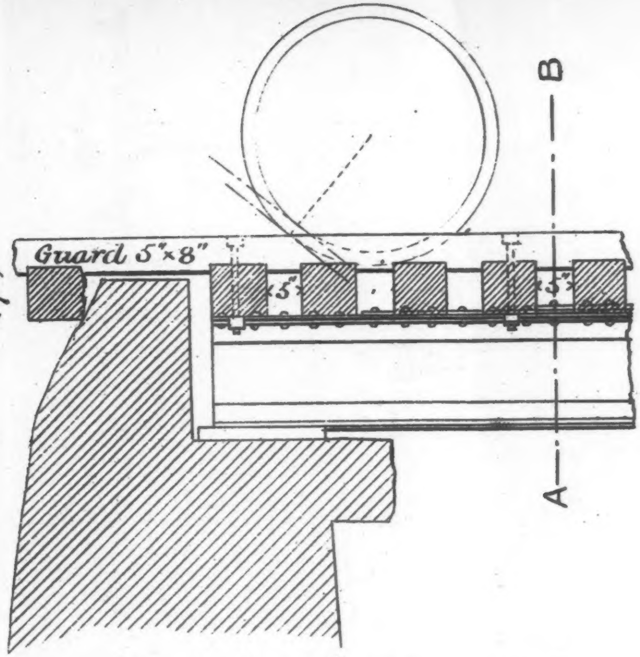
In conclusion, I would note, as a corollary to this discussion, that the treatment of derailments gives an argument for avoiding middle trusses on double-track bridges, which may serve to turn the scale in favor of two trusses only in some cases.

Successful experiments have been made by Mr. McClure, Chief Engineer of the Chicago, Burlington and Quincy R. R. system, with a re-railing arrangement at the ends of bridges, and it is possible that this will be substituted for the simple drawing together of the guard timbers, but it does not conflict with the other points above advocated.



Scale 1" = 2'

Cross Section on A-B



Longitudinal Section on C-D

Scale 1" = 4'

Plan of Point

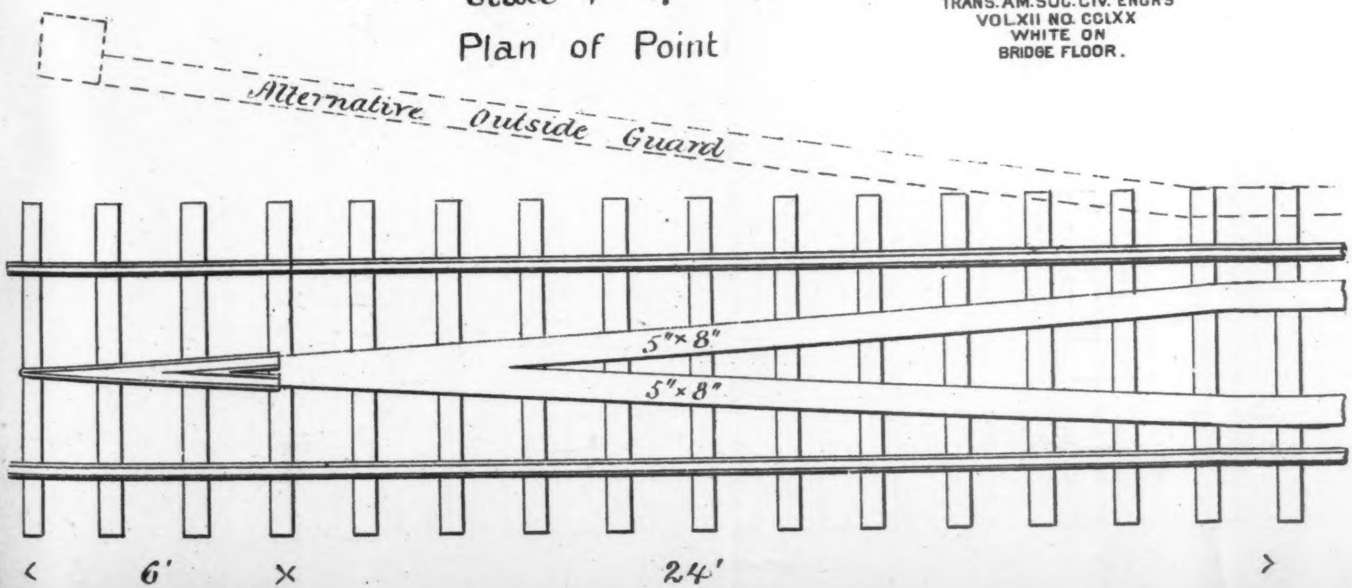


PLATE XXX
TRANS. AM. SOC. CIV. ENG'RS
VOL. XII NO. CCLXX
WHITE ON
BRIDGE FLOOR.